pp Elastic Scattering in FELIX: Physics Goals

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1. Goals in the small momentum transfer region $(0 \lesssim |t| \lesssim 0.5(\text{ GeV}/c)^2)$ [1]:

a) Determine whether the measured value of σ_{tot} corresponds to a $\ln^2 s/s_o$ growth, i.e., whether this value reflects the maximum rate of increase of σ_{tot} with energy allowed by unitarity and analiticity ("saturation" of the Froissart-Martin bound). Present status of the growth of total cross section with energy is shown in Fig.1 [2]. The asymptotic energy dependence of σ_{tot} for the various curves is taken to be of the form: $\sigma_{\text{tot}} \propto (\ln s/s_o)^\gamma$. The best fit (solid line) corresponds to $\gamma = 2.25$ and favors the $\ln^2 s$ dependence. The dotted curve corresponds to the $\ln s$ growth ($\gamma = 1$). Clearly, accurate measurement of σ_{tot} should be able to distinguish between the $\ln^2 s$ and the $\ln s$ growth.

b) See whether the mesured value of ρ (ratio of the real part to the imaginary part of the forward scattering amplitude) helps to pin down better the asymptotic behavior of the total cross section via dispersion relation. This implies carrying out a dispersion relation analysis similiar to that of Augier *et al.* [2]. Also, study the energy dependence of the forward diffraction slope B $\left(\frac{d\sigma}{dt} \sim e^{Bt}\right)$. The continuous increase of B implies a continuous shrinkage of the diffraction peak (alternatively, a continuous increase in size of the absorptive pp interaction region). Any dynamical mechanism of diffraction scattering has to explain satisfactorily the quantitative behavior of B.

2. Goals in the large momentum transfer region $(8 \lesssim |t| \lesssim 25 \text{ (GeV}/c)^2)$:

a) Determine whether the perturbative QCD behavior has set in. Elastic scattering in perturbative QCD has been studied by Sotiropoulos and Sterman [3,4]. The scattering originates from a valence quark in one nucleon scattering off a valence quark in the other nucleon. The differential cross section behaves as

$$\frac{d\sigma}{dt} \sim \frac{d\sigma_{qq}}{dt}\left(\frac{1/Q^2}{R_p^2}\right)^8 , \tag{1}$$

where $Q = \sqrt{|t|}$. The last factor in (1) arises from the requirement that each spectator quark has to be within a transverse distance of $1/Q$ of the colliding valence quark [3]. The valence quark-quark scattering in (1) is assumed to be due to a color singlet amplitude behaving as s/t, so that $\frac{d\sigma_{qq}}{dt} \sim t^{-2}$. For large $|t|$, this leads to the power fall-off behavior [4]:

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$$\frac{d\sigma}{dt} \sim \frac{1}{t^{10}}\,, \tag{2}$$

which corresponds to the dimensional counting rule. The perturbative QCD behavior (2) can be preceded by an intermediate behavior $\frac{d\sigma}{dt} \sim t^{-8}$. The latter occurs when the three valence quarks from one nucleon independently scatter off the three valence quarks from the other nucleon — a scattering process known as the Landshoff mechanism [5].

b) Examine whether the differential cross section behaviors predicted by the impact picture approach [6] and by the Regge-pole type approach[7] are borne out. At LHC energies, calculations based on these approaches predict oscillating differential cross section with secondary minima and maxima. Fig.2 shows quantitative predictions of the impact picture approach and Fig.3 that of the Regge-pole type approach.

c) Determine whether a significant change in the slope of the differential cross section occurs at $|t| \simeq 9$ (GeV$/c)^2$. pp elastic cross section at the ISR at $\sqrt{s} = 53$ GeV [8] shows a rapid fall-off: $\frac{d\sigma}{dt} \sim e^{-a\sqrt{|t|}}$ (Orear fall-off) in the momentum transfer range $2 \lesssim |t| \lesssim 8$ (GeV$/c)^2$. Around 9 (GeV$/c)^2$, the differential cross section shows a flattening behavior (of course, with large error bars). This is suggestive of the onset of a perturbative QCD behavior. An accurate measurement of $\frac{d\sigma}{dt}$ in this region is, therefore, of crucial importance.

Phenomenological analysis of elastic ISR and SPS Collider data [9] suggests that the nucleon is a soliton (a Skyrmion) embedded in a condensed ground state of quarks and antiquarks — a $q\bar{q}$ condensate [10]. In such a description, the change in the behavior of $\frac{d\sigma}{dt}$ at $Q \simeq 3$ GeV$/c$ reflects a transition of the elastic scattering process from a non-perturbative regime to a perturbative regime. If the scattering process in the latter regime is due to the valence quark-quark scattering, then the above behavior of $\frac{d\sigma}{dt}$ implies a valence quark bag of size $R \sim \frac{1}{3\ \mathrm{GeV}/c} = 0.07$F [10]. Interestingly enough, Sotiropoulos and Sterman [4] have arrived at a similar conclusion from their analysis of large $|t|$ pp elastic data. They find that the transverse size of the valence three-quark state has to be < 0.2F. It will be exciting, if a systematic precise measurement of elastic $\frac{d\sigma}{dt}$ over a wide range of $|t|$ at $\sqrt{s} = 10$ TeV does indicate the existence of a valence quark bag of size $R \simeq 0.1$F in a nucleon.

3. Goals in the intermediate momentum transfer region ($0.5 \lesssim |t| \lesssim 8$ (GeV$/c)^2$):

Investigate the dynamical mechanisms that produce the first minimum and the second maximum in the differential cross section, and then a rather smooth fall of $\frac{d\sigma}{dt}$ at large $|t|$ values. In ISR at $\sqrt{s} = 53$GeV [8], the latter corresponds to a fall of four orders of magnitude in the range $2 \lesssim |t| \lesssim 8$ (GeV$/c)^2$. Various theoretical models have been proposed to explain the behavior of $\frac{d\sigma}{dt}$ in this range. In the Donnachie-Landshoff model [11], where the forward elastic scattering is due to a Pomeron with an intercept greater than 1 ($\alpha_P(0) = 1 + \epsilon$, $\epsilon \simeq 0.08$), the first minimum, or, the dip is produced primarily by the destructive interference between the single Pomeron and the double Pomeron exchange amplitudes. A C-odd three-gluon exchange amplitude is also required in the dip region and in the large $|t|$ region [12]. In the impact picture of Bourrely, Soffer, and Wu [6] (essentially, an optical model description), the dip, the second maximum, and the subsequent fall are all due to a purely absorptive energy-dependent interaction (Fig.2). Desgrolard, Giffon, and Predazzi [7] have taken an eclectic approach, where they combine various earlier approaches based on Regge dynamics (poles plus cuts). They find that an Odderon (a C-odd asymptotic amplitude) contribution is needed and that structures (shoulders or dips) develop as we go from ISR to LHC energies (Fig.3). In the soliton model of the nucleon with an outer cloud of $q\bar{q}$ condensate, the elastic scattering in the intermediate region originates from the scattering of one soliton off the other via ω exchange, while the outer condensates overlap and interact independently [10]. The ω – soliton interaction arises from the coupling of ω as a gauge boson to the (topological) baryonic charge distribution, which produces the soliton. This scattering mechanism leads to a smooth exponential fall-off $\left(\frac{d\sigma}{dt} \sim e^{-a\sqrt{|t|}}\right)$. Its interference with the diffractive amplitude produces the forward dip in pp, while its breakdown (because of chiral phase transition) signals the onset of perturbative QCD (Fig.4) [9,10]. Clearly, accurate measurement of $\frac{d\sigma}{dt}$ in the intermediate momentum transfer region will provide a vital testing ground of various theoretical ideas, which will, of course, have to relate with the forward diffraction amplitude and the large $|t|$ perturbative QCD amplitude.

Accurate measurement of the elastic pp differential cross section at $\sqrt{s} = 10$ TeV and $0 \lesssim |t| \lesssim 25$ (GeV/$c)^2$ in FELIX will be a unique contribution. It will parallel the pp differential cross section measurement of an earlier era at $\sqrt{s} = 53$ GeV and $0 \lesssim |t| \lesssim 10$ (GeV/$c)^2$ in ISR [8,13]. The ISR measurement has served as the benchmark for theoretical investigations in pp elastic scattering for the last two decades. If the FELIX measurement plays a similiar role in the new domain of energy opening before us, then that alone will make this undertaking worthy of our best effort — quite aside from the important physics goals that we have outlined above.

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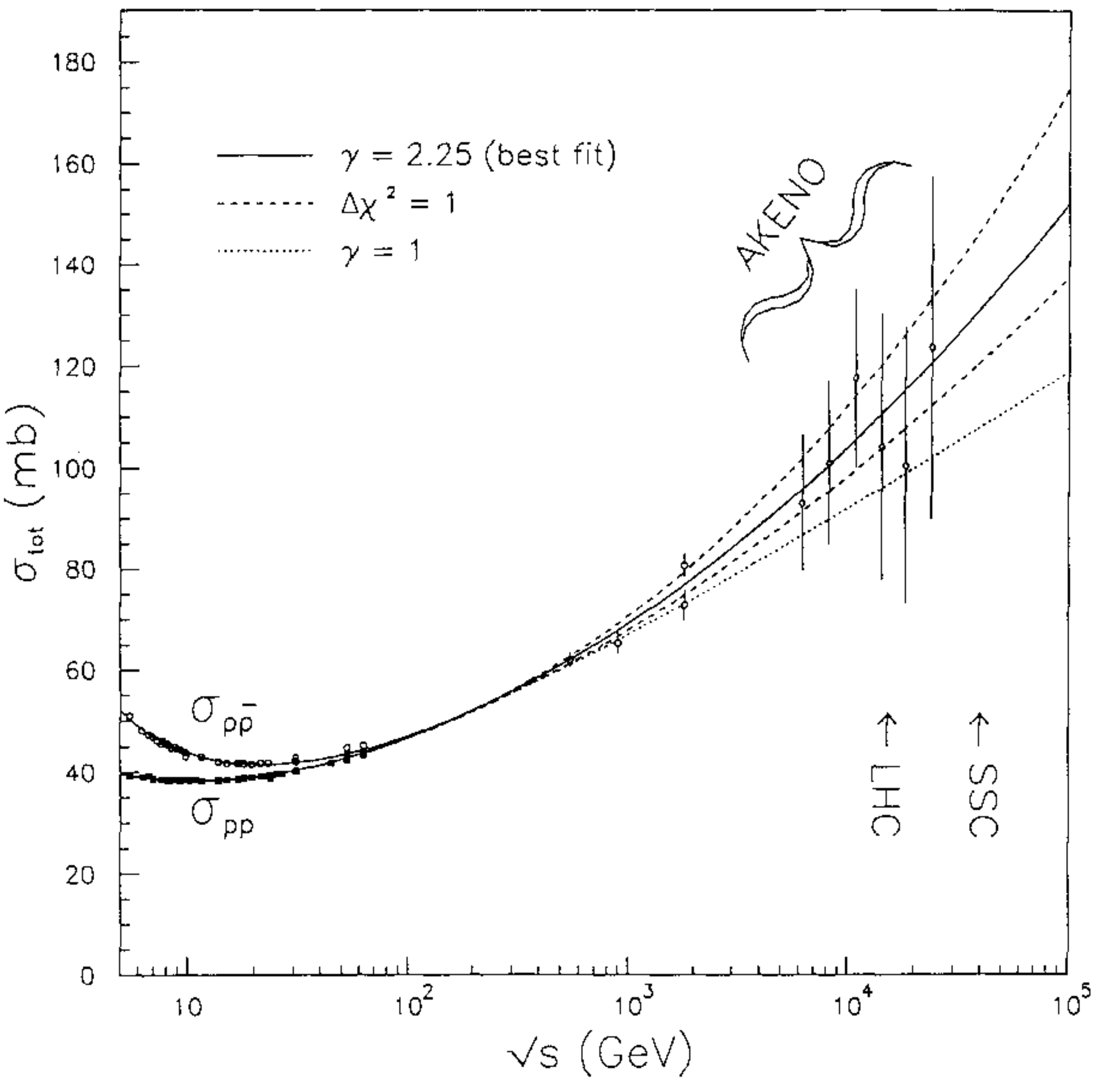

Fig. 1. Growth of the total cross section with energy (Augier *et al.*, Ref. [2]).

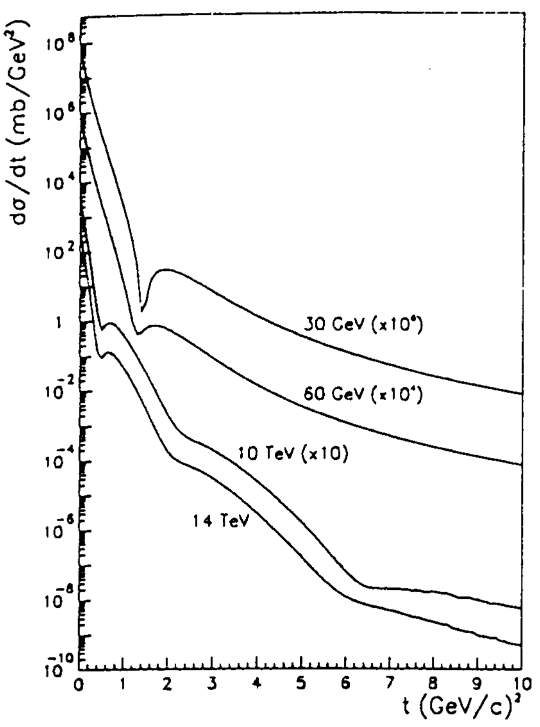

Fig. 2. $\frac{d\sigma}{dt}$ in the impact picture of Bourrely *et al.* (from Ref [1]).

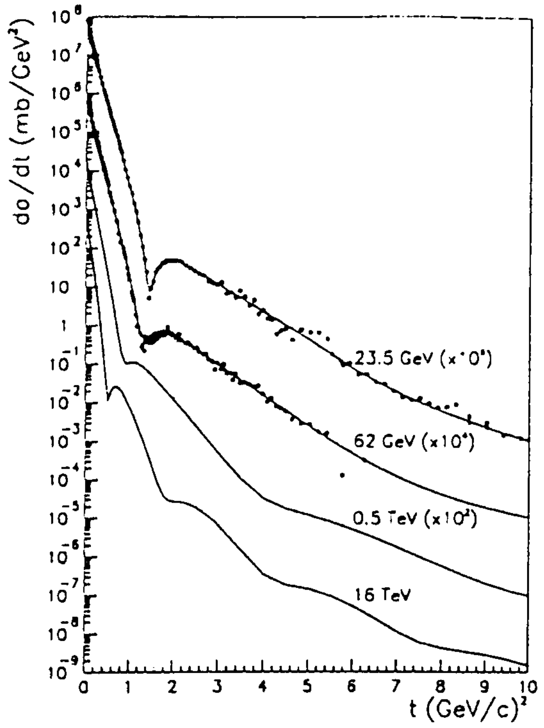

Fig. 3. $\frac{d\sigma}{dt}$ in the Regge-Pole analysis of Desgrolard *et al.* (from Ref. [1]).

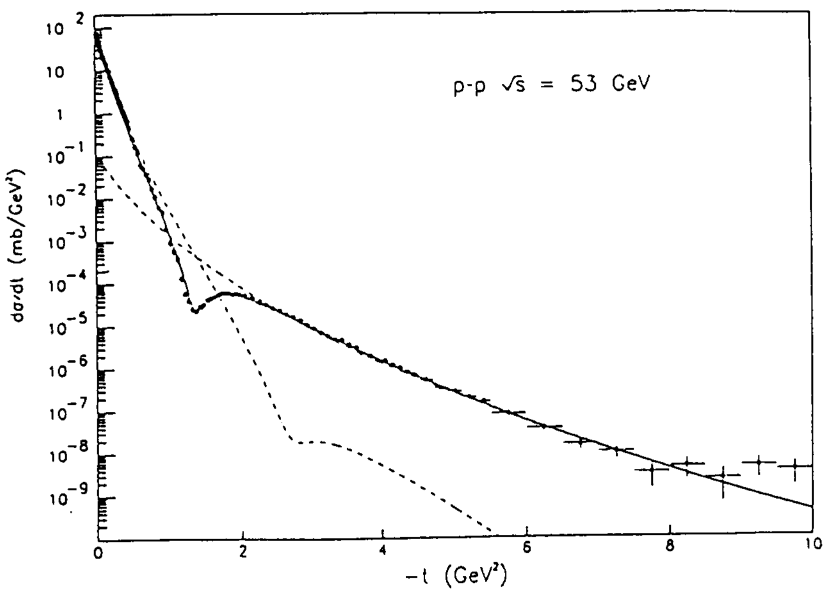

Fig. 4. $\frac{d\sigma}{dt}$ at $\sqrt{s} = 53$ GeV in the soliton model of the nucleon with an outer cloud of $q\bar{q}$ condensate (Refs. [9],[10]).